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TECHNICAL NOTE

D-367

SIMULATOR MOTION EFFECTS ON A PILOT'S ABILITY TO
PERFORM A PRECISE LONGITUDINAL FLYING TASK

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON

May 1960

(NASA-TN-D-367) SIMULATOR MOTION EFFECTS ON
A PILOT'S ABILITY TO PERFORM A PRECISE
LONGITUDINAL FLYING TASK (NASA. Langley
Research Center) 12 p

N89-70770

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SUMMARY

A program was conducted on the NASA normal acceleration and pitch (NAP) simulator to determine the effect that body-motion cues have on the pilot's ability to perform a precision close-coupled tracking task. These tests were conducted with heavy stick-force gradient and with zero-stick-force gradient over a range of longitudinal stability conditions. Pilots controlled the simulator from both a fixed and a moving cockpit.

The results indicate that there was improvement in pilot performance due to motion cues over the stability range tested. The motion cues appreciably improved the performance of both pilots when the feel forces were absent. The pilots always preferred to be supplied with motion cues. In the absence of feel forces, confusion was exhibited by one pilot as to the proper direction to execute control when bodily-motion cues were not provided.

INTRODUCTION

With the increase in the use of simulators to study piloting problems there is a desire to determine the importance of providing body-motion cues. Quantitative tests, therefore, have been made utilizing the normal acceleration and pitch simulator (NAP) at the Langley Research Center to study the effects of vertical and pitching motions upon the pilot's ability to control in the longitudinal mode. This simulator includes a cockpit which pitches and moves vertically in response to longitudinal control inputs by the pilot. (See ref. 1 for complete description.) In previous tests with this simulator (ref. 1), the effect of providing or omitting pitching motion in conjunction with vertical motion was studied. The pilots expressed the opinion that pitching motion was desirable; however, quantitative scoring data showed that pitching motion had only a small effect upon the controllability for the specific task presented by the simulator.

In the present study a fixed cockpit was mounted beside the moving cockpit of the NAP simulator and pilot performance was obtained for a specific task with no motion and for the same task with both pitch and vertical motion. Tests were made with a wide range of maneuver margin accompanied by the expected large variation of airplane short-period characteristics. The same control system with the same two widely different stick-centering spring-force gradients (0 and 240 pounds per inch) were used in both cockpits. The results of these tests are presented herein.

SYMBOLS

$\ddot{\theta}$	pitching angular acceleration, deg/sec ²
δ_T	longitudinal control surface position, deg
g	acceleration of gravity, g units
α	angle of attack, deg
δ_S	control-stick deflection, deg (1° of stick motion is equal to 0.45 inch of stick grip travel)

DESCRIPTION OF APPARATUS

The NAP simulator consists of a cockpit that is able to rotate in pitch and to move vertically in response to motions of the control stick located in the moving cockpit. A detailed description of the simulator is given in reference 1. For the present tests, a stationary cockpit was mounted adjacent to the movable cockpit at a height midway of the range of travel of the movable cockpit. An overall view of this arrangement is shown in figure 1. The same cockpit control elements (the stick, the feel system, the stick position transmitter, and the screen and target system (ref. 1)) were used for both cockpits. The pilot's task consisted of trying to keep a sighting image which was projected from the moving cockpit aligned with a target as the target moved up and down. The "stationary cockpit" condition is one in which the pilot controlled the moving cockpit from the stationary cockpit and therefore was provided with the visual cues of target and sighting image motion only. In the "moving cockpit" configuration, the pilot occupied the moving cockpit and therefore was provided with body pitching and vertical motion cues in addition to the visual cues supplied by the target and sighting image motions.

A partition was mounted between the moving cockpit and the fixed cockpit to prevent the pilot from seeing the moving cockpit when seated in the fixed cockpit. Although the target and sighting image projected from the moving cockpit were viewed from the fixed cockpit along lines not perpendicular to the screen, the effect of the resulting parallax on the pilot's ability to aline the image with the target was felt to be negligible.

TESTS, PROCEDURES AND CONDITIONS

Figure 2 shows the ranges of airplane short-period natural frequency and damping ratio that were covered in the stability range tested. The period and damping curves are generally representative of those for present-day fighters flying at high speeds. The quantities in figure 2 are shown as function of the parameter stabilizer angle per g (δ_T/g) expressed in degrees per g. This parameter was chosen as a basic plotting quantity because it is linearly related to maneuver margin and is not influenced by changes in stick-centering spring-force gradient. For these tests, the steady-state normal-acceleration response in g per unit angle of attack was held at 1.0. The control effectiveness in terms of pitching acceleration produced per unit of stabilizer angle travel $\ddot{\theta}/\delta_T$ was held constant at 40 radians per second per second per radian of stabilizer angle δ_T . One other important parameter defining the simulator test conditions is the ratio δ_T/α . For the most forward center-of-gravity condition tested this ratio was always 1.0 and, as the center of gravity was moved rearward, this ratio was decreased linearly with the parameter δ_T/g .

Only one value of control system gearing, $\delta_S/\delta_T = 2.0$ degrees/degree was used. Two stick-centering spring-force gradients were tested, 240 pounds per inch and zero. As shown in reference 1, the value of 240 pounds per inch, although apparently high for a normal airplane stick-force gradient was a desirable value for the control task used on the simulator. The value of zero was very undesirable.

As in the tests of reference 1, a repeating trapezoidal-wave-form target motion having a period of 12 seconds was used. The time history of this motion is shown in figure 3. It should be noted that to obtain good performance of this task requires extreme precision on the part of the pilot. This task more closely represents a close formation flying or refueling type of operation and should not be confused with a long-distance tracking task.

The pilot's performance was judged primarily on the basis of the integrated absolute error measurement between the target and sighting image. This integrated error was used in calculation of a quantity called "performance index."

$$\text{Performance index} = \frac{(\text{Error})_{\text{Cockpit motionless}} - (\text{Error})_{\text{Actual}}}{(\text{Error})_{\text{Cockpit motionless}}}$$

All the test data are presented in the form of performance index plotted against δ_T/g . This performance index is fully explained in reference 1.

Two NASA test pilots served as simulator pilots for all the tests presented in this paper.

RESULTS AND DISCUSSION

The results obtained by both pilots are shown in figure 4. The data are presented in terms of the performance index plotted against the stability parameter δ_T/g with stick-centering gradients of 0 and 240 pounds per inch for both the moving- and the fixed-cockpit configurations. The figure shows that over the stability range tested the performance levels for both pilots are better for the cases with the high-stick-force gradients. With either force gradient, both pilots generally produce higher indices when controlling from the moving cockpit, the effect of motions being most beneficial for the case of zero-stick-force gradients. The pilots received the feel of motion principally from the motion due to normal acceleration inasmuch as the pitching motions were rather small. Both pilots generally could tolerate less stability when motion cues were present than when only visual cues were present.

The pilots commented that the absence of motion made all the test conditions more difficult to control but the differences were most apparent for the condition of zero-force gradient. With this condition one of the pilots often applied control in the wrong direction and lost control of the simulator. This particular difficulty was never experienced when the motion cues were present.

On the basis of these tests, it appears that vertical motion cues reduce considerably the difficulties associated with precision flying involving small changes in altitude.

CONCLUSIONS

As a result of tests over a specified large stability range to determine the effects of providing vertical motion and pitching rotations on the pilot's ability to perform a precise formation flying task with the NAP simulator, the following general conclusions were indicated:

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1. The ability of the pilots to perform a close-coupled tracking task was better when performed from a moving cockpit than when performed from a fixed cockpit. The ability of the pilots to perform this task was further enhanced by the inclusion of high-stick-force gradients.

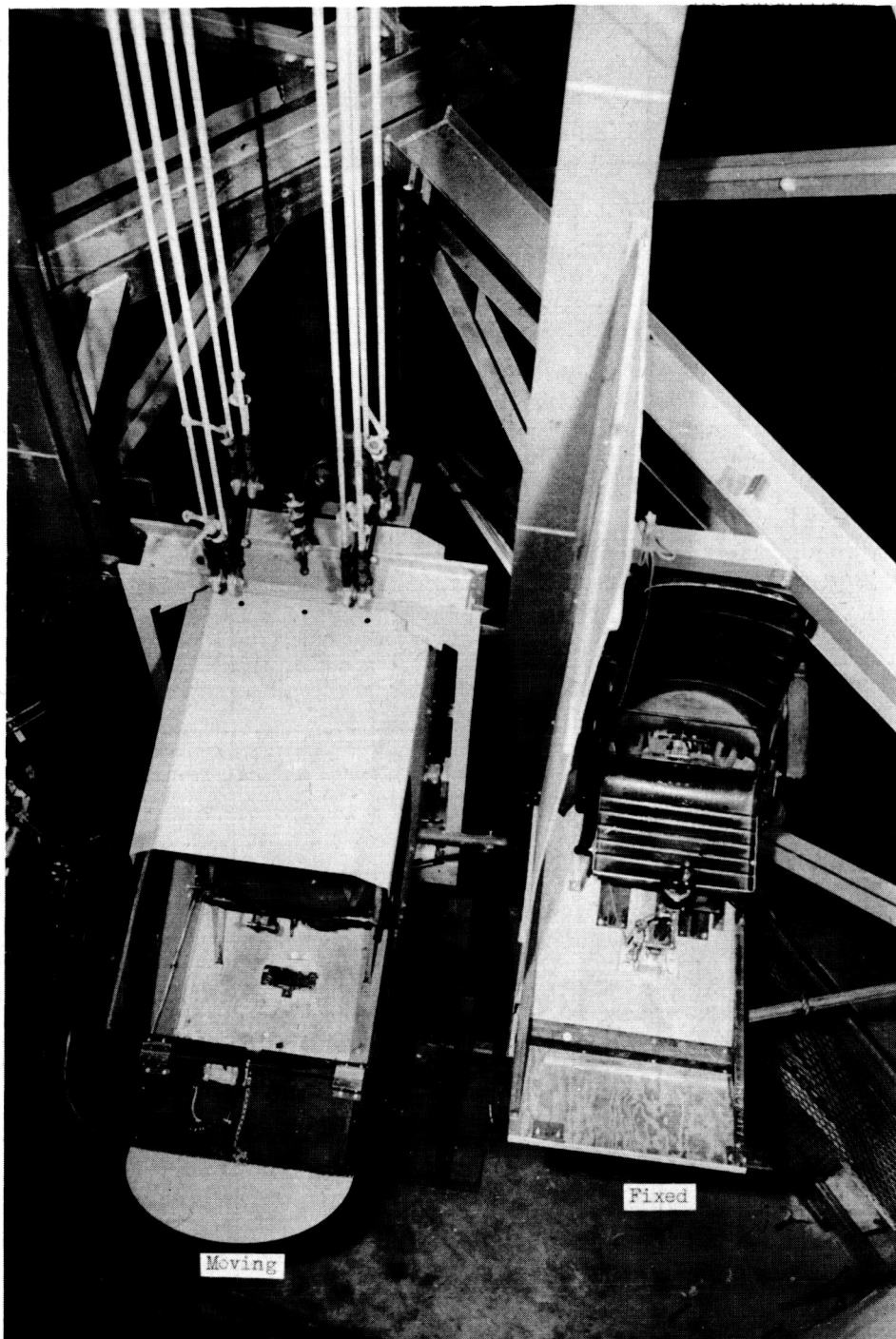
2. The effect of motions was most beneficial at zero-stick-force gradient. It should be pointed out that the motion cues given to the pilot were principally due to vertical motion inasmuch as the pitching motions were rather small.

3. The pilots always preferred to be supplied with motion cues. In the absence of control feel forces, one pilot exhibited confusion as to the proper direction that the stick should be moved to retain control in conditions of poor stability; such confusion was not evident when the motion cues were being experienced by the pilot.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., January 22, 1960.

REFERENCE

1. Brown, B. Porter, and Johnson, Harold I.: Moving-Cockpit Simulator Investigation of the Minimum Tolerable Longitudinal Maneuvering Stability. NASA TN D-26, 1959.



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Figure 1.- A general top view photograph of the moving and fixed cockpit.

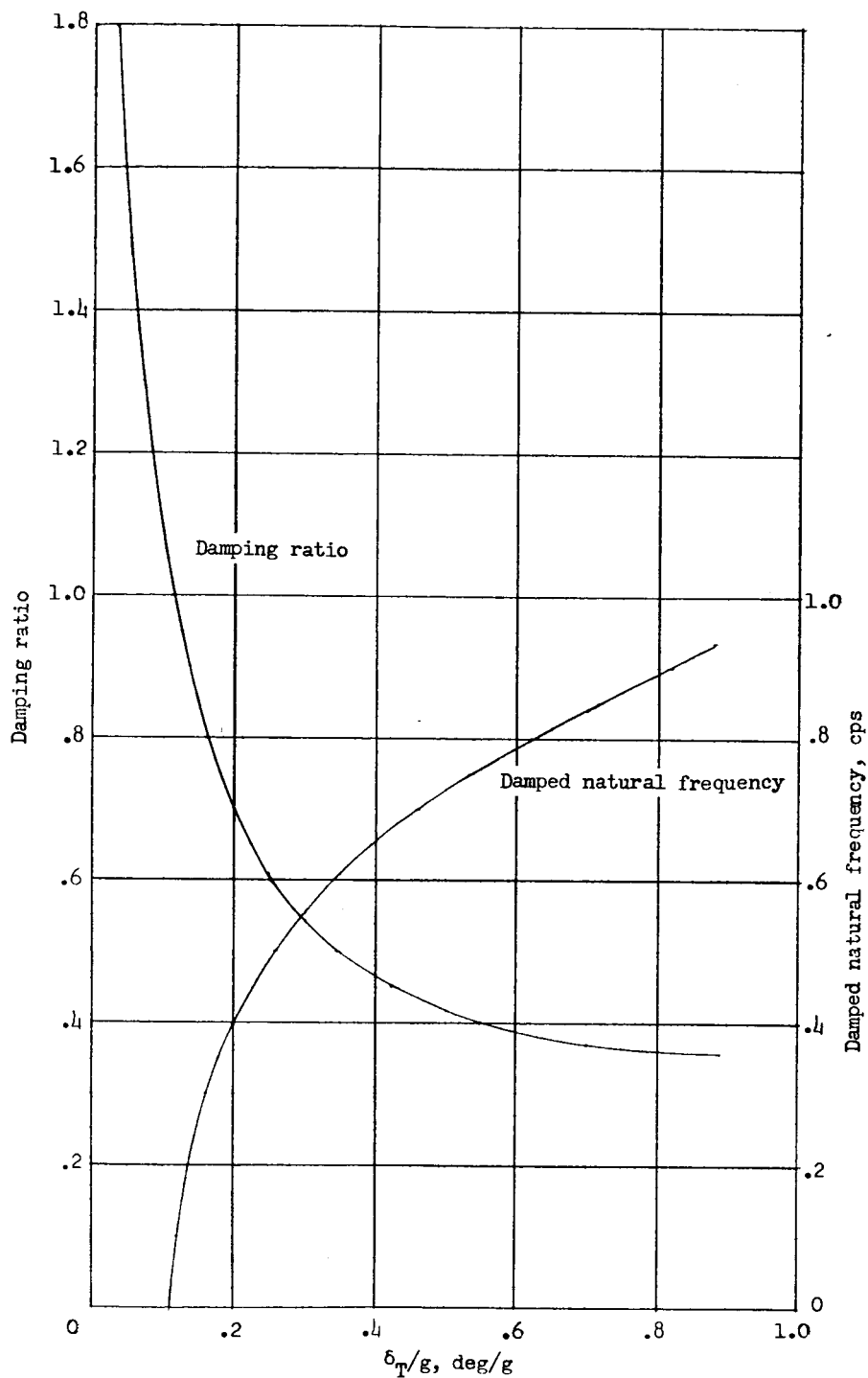


Figure 2.- Damped natural frequency and damping characteristics of NAP simulator as functions of the parameter stabilizer angle per g.

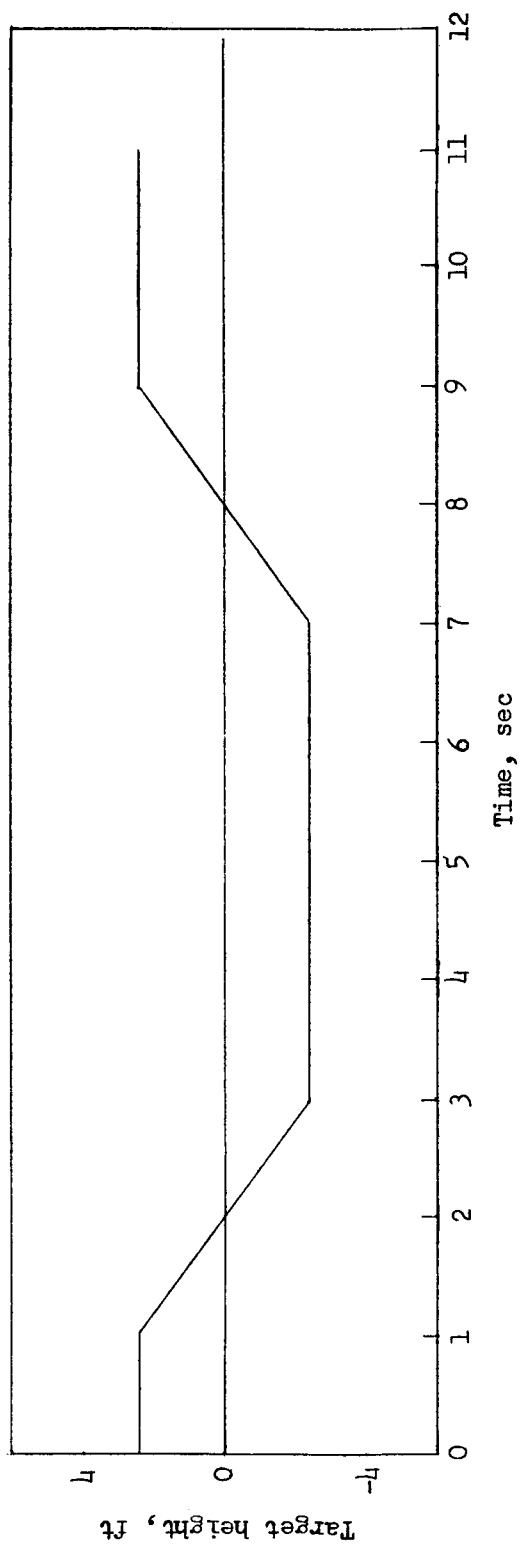
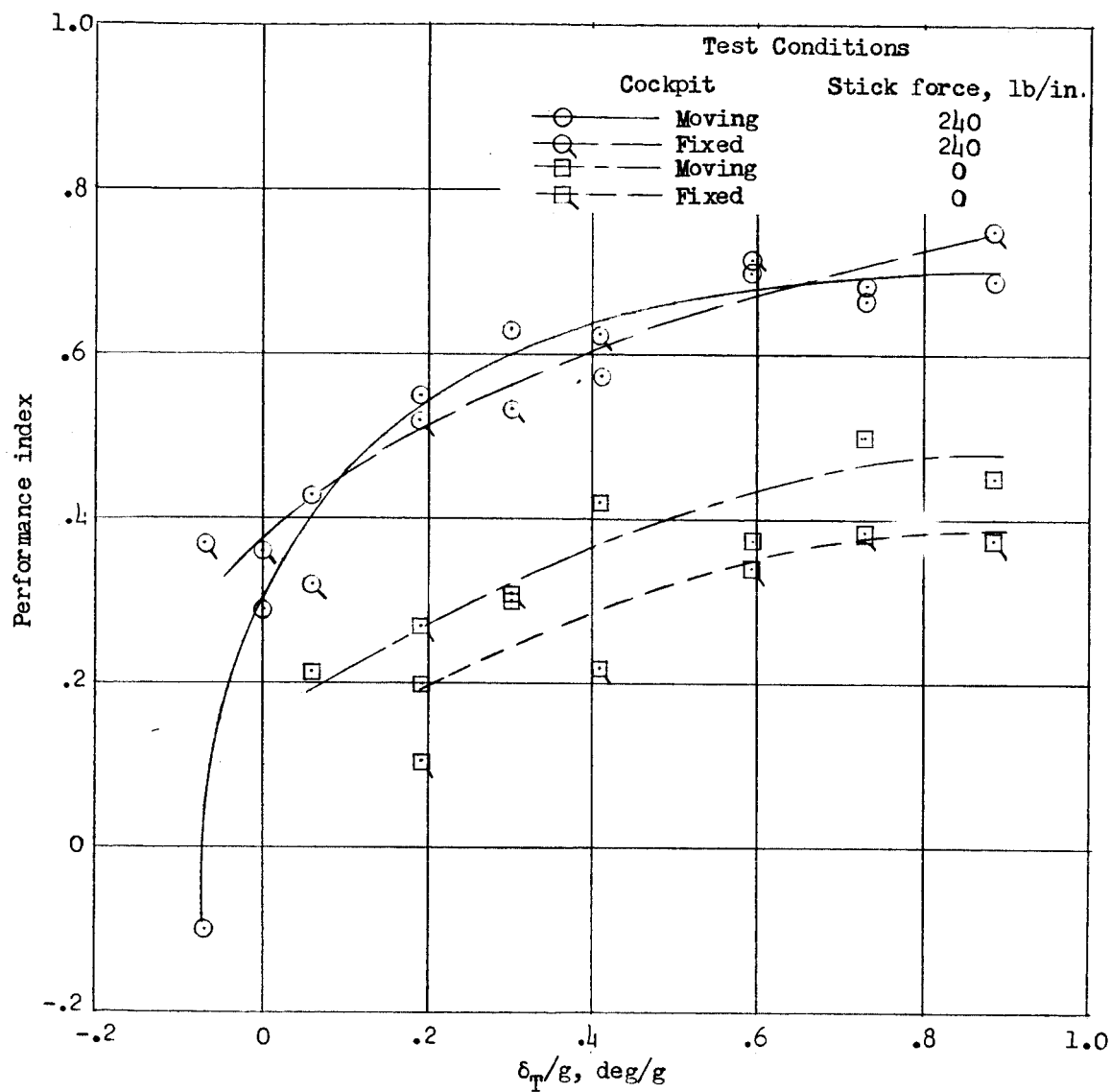
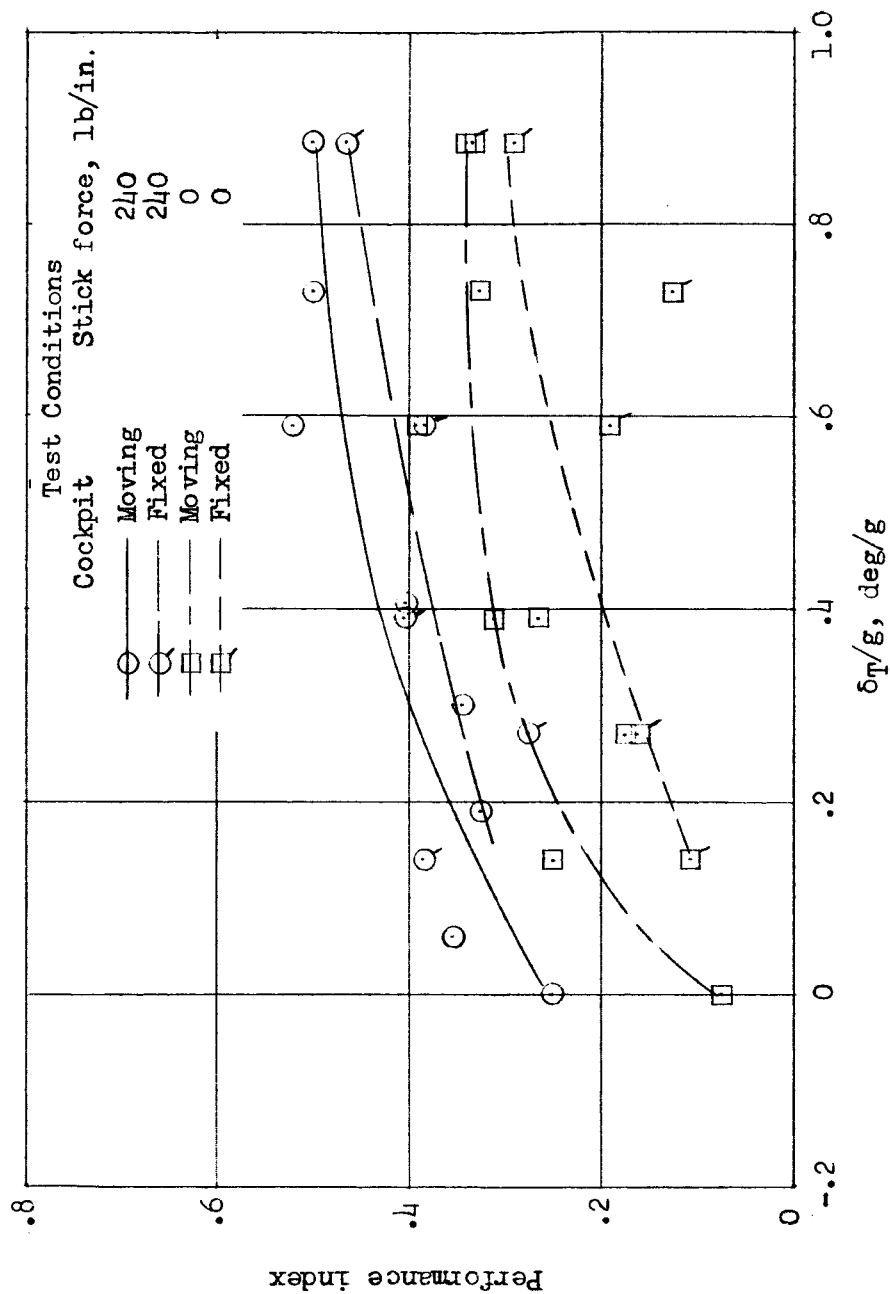


Figure 3.- Time history of the trapezoidal-wave-form target motion.



(a) Pilot A.

Figure 4.- Performance indices plotted as a function of the parameter stabilizer angle per g for moving and fixed cockpit with and without stick forces.



(b) Pilot B.

Figure 4.- Concluded.